Observation of $B \to \varphi K \gamma$ and Measurement of time-dependent CP violation
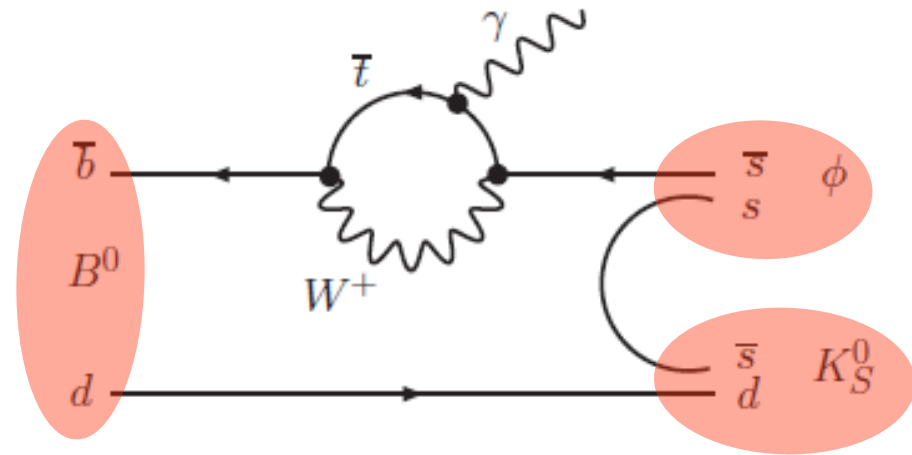
Himansu Sahoo

University of Hawaii

for the Belle Collaboration

Radiative Penguin

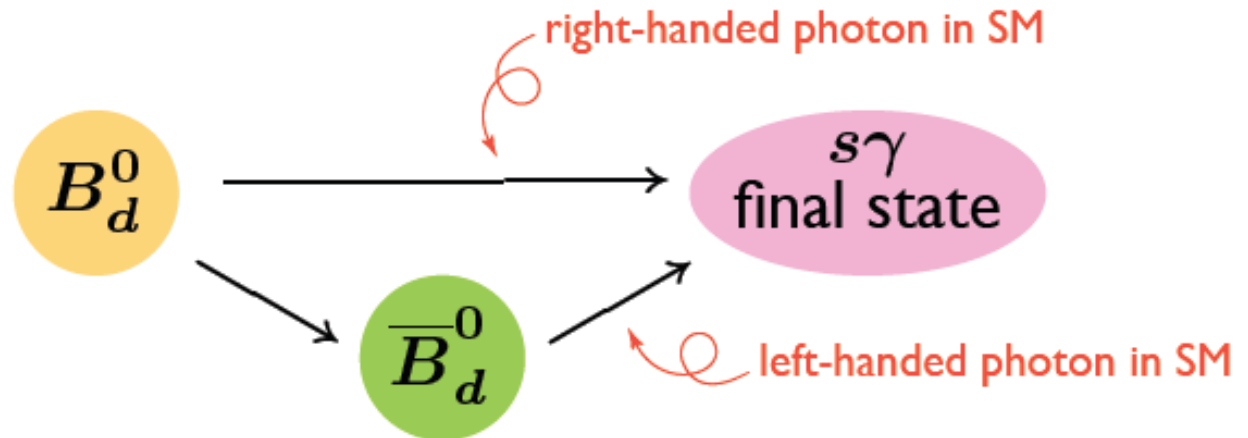- Radiative b→sγ decays : excellent probe for physics beyond the SM.

- <u>F</u>lavor <u>C</u>hanging <u>N</u>eutral <u>C</u>urrent processes.

- Forbidden at tree-level in the SM, but allowed through loop (penguin) diagrams.

- Non-SM particles can contribute to the loop.

Search for Right-Handed currents

right-handed photon in SM

B^0_d → $s\gamma$ final state

$\overline{B}^0_d$

left-handed photon in SM

- In SM, radiative photon from b→sγ transition is flavor-specific.

- $B^0 \leftrightarrow \overline{B^0}$ interference can occur only through a helicity flip.

- The CP asymmetry in SM is suppressed by the quark mass ratio.

$$S \approx -2(m_s/m_b)\sin(2\phi_1) \quad \sim 0.03$$

- A large CP asymmetry will be a clear hint of new physics (LRSM model).

- AGS method is valid for any $B^0 \rightarrow P^0 Q^0 \gamma$ with C eigenstate mesons (e.g. $B^0 \rightarrow \varphi K_s \gamma$)

TCPV in b→sγ modes

$$B^0 \rightarrow K_S \pi^0 \gamma$$

Vertex is from Ks →$\pi^+\pi^-$ (both pions are required to have enough hits in the silicon)

$$\mathcal{S}_{K_S\pi^0\gamma} = -0.10 \pm 0.31 \pm 0.07$$
$$\mathcal{A}_{K_S\pi^0\gamma} = -0.20 \pm 0.20 \pm 0.06$$

$$B^0 \rightarrow K_S \rho^0 \gamma$$
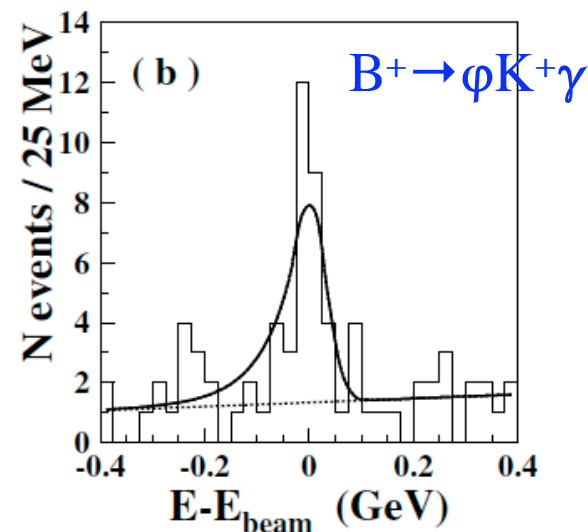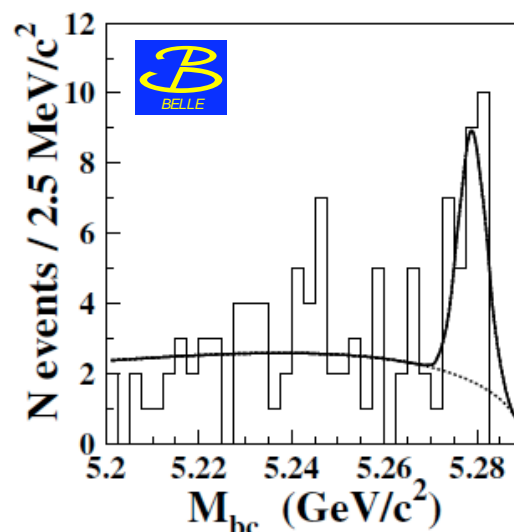
Vertex is from ρ^0→$\pi^+\pi^-$ (no K$_S$ vertex is needed)

$$\mathcal{S}_{K_S\rho^0\gamma} = 0.11 \pm 0.33^{+0.05}_{-0.09}$$
$$\mathcal{A}_{K_S\rho^0\gamma} = 0.05 \pm 0.18 \pm 0.06$$

Consistent with the SM expectation

SIG

BG

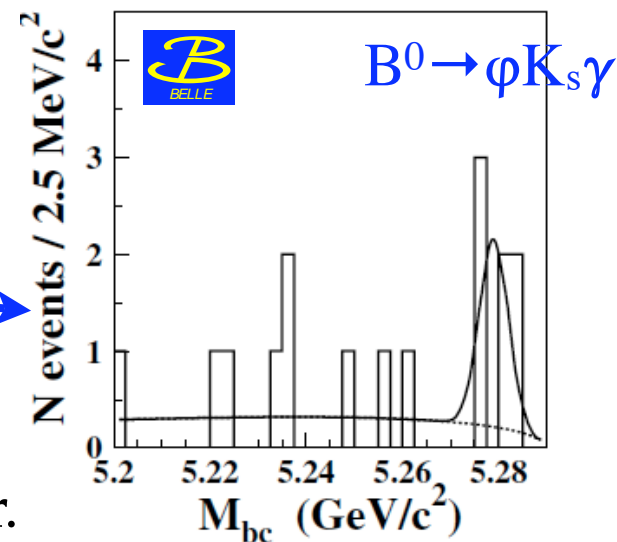r>0.5
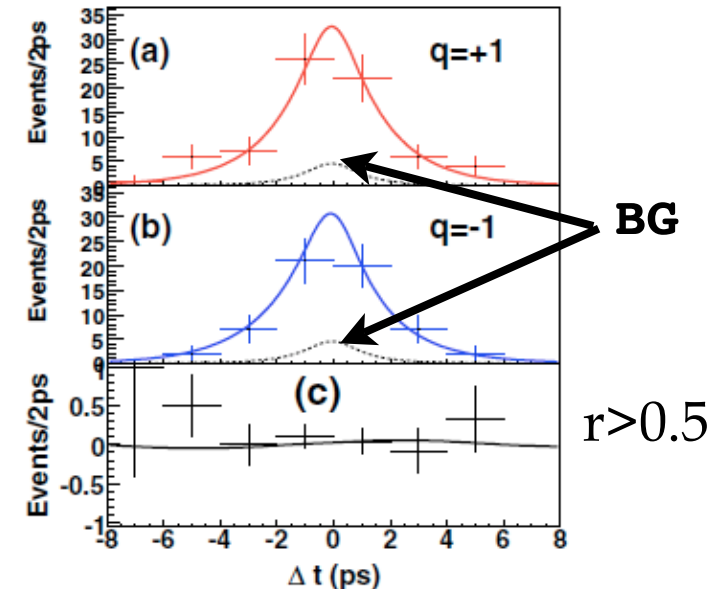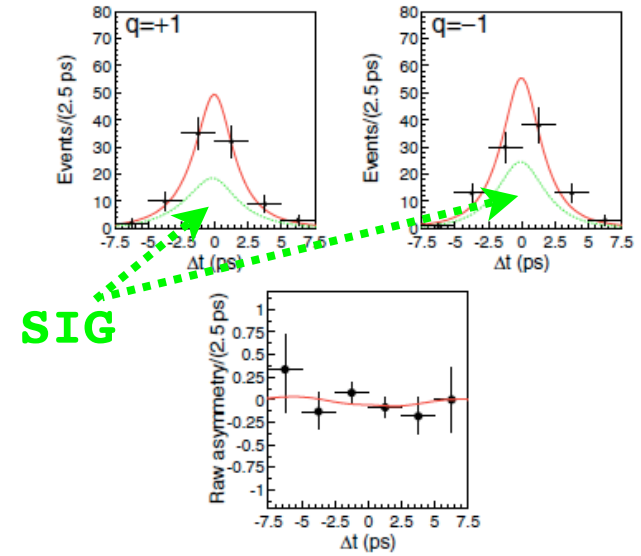
Previous Measurements of B→φKγ

PRL 92, 051801 (2004)

96 M B$\overline{\text{B}}$

First observation of B$^+$→φK$^+$γ by Belle
(21.6±5.6 events, 5.5 significance)

Upper limit on B^0→φK$_s$γ (5.8±3.0 events)

Now Belle has a data sample nearly eight times larger.

Signal Extraction

$$B^0 \to \phi\, K_S^0\, \gamma$$

$$K^+ K^- \quad \pi^+ \pi^-$$
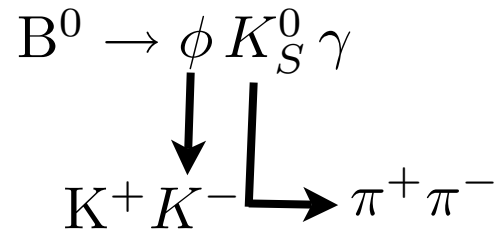
- B candidates are selected using ΔE and M_{bc}

$$\Delta E \equiv E_B^* - E_{beam}^* \qquad M_{bc} \equiv \sqrt{(E_{beam}^*)^2 - (p_B^*)^2}$$

- 2D fitting method to ΔE-M_{bc} (unbinned extended maximum likelihood) fit region :

$$(-0.3\,\text{GeV} < \Delta E < 0.3\,\text{GeV})\ \&\&\ (5.2\,\text{GeV}/c^2 < M_{bc} < 5.29\,\text{GeV}/c^2)$$

Background Rejection

- Continuum : separate $B\overline{B}$ (spherical) from continuum (jet-like) using a likelihood derived from event shape variables and B direction. => removes 91% continuum while retaining 76% of signal.
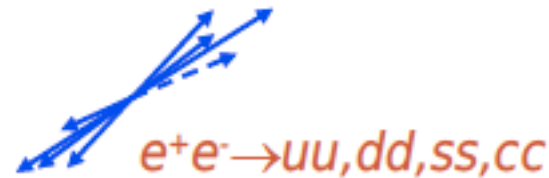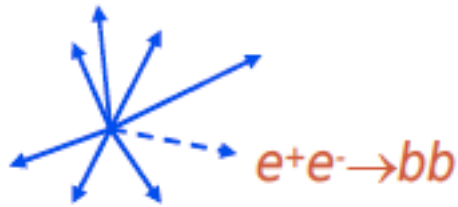
- $b \rightarrow c$ peaking backgrounds ($D^0\pi^0, D^0\eta$) are removed by the D^0 veto (neutral mode) (1.842< M(φKs)<1.878 GeV)

- Nonresonant $K^+K^-K\gamma$ is determined to be 13% of the signal using the φ mass sideband in data [1.05-1.3 GeV]
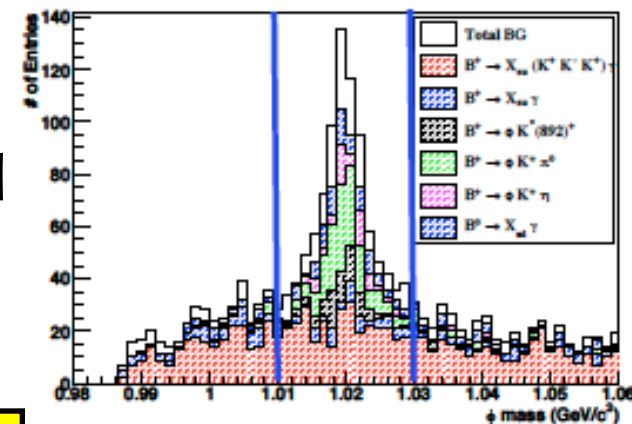
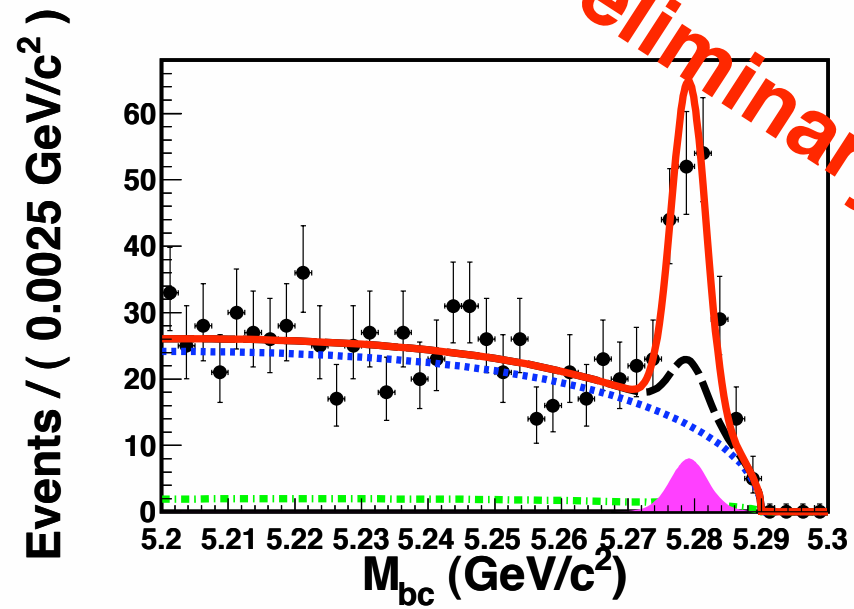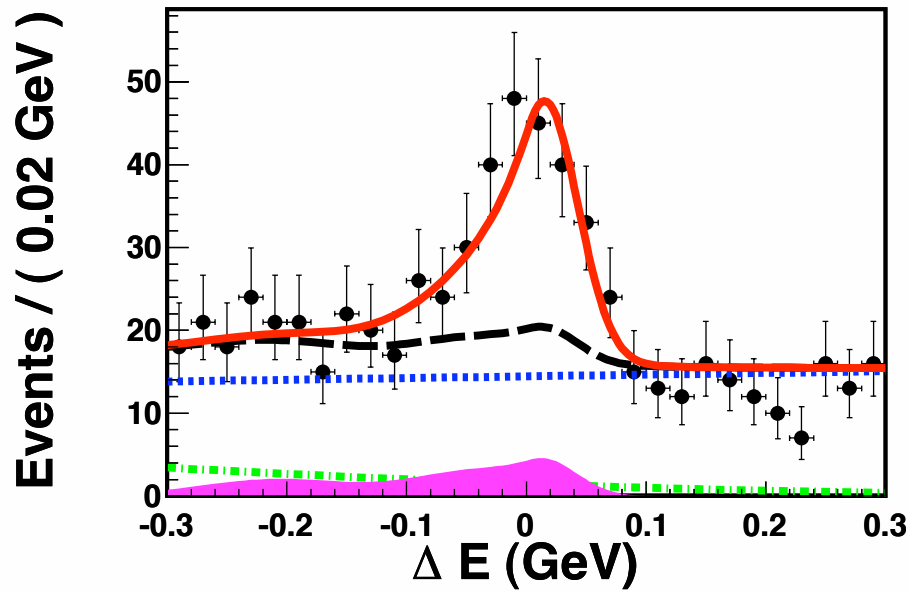**Efficiency : (15.3±0.1)% for charged and (10.0±0.1)% neutral mode**

$772\,\mathrm{M}\,\mathrm{B\overline{B}}$

arXiv: 0911.1779

$B^+ \to \varphi K^+ \gamma$ Data

Preliminary!

136±17 Events

$$\mathcal{B}(B^+ \to \varphi K^+ \gamma) = (2.34 \pm 0.29 \pm 0.23) \times 10^{-6}$$

Significance : 9.6σ (including systematics)

- ● **Data**
- ─ **Signal**
- ─ **Total BG**
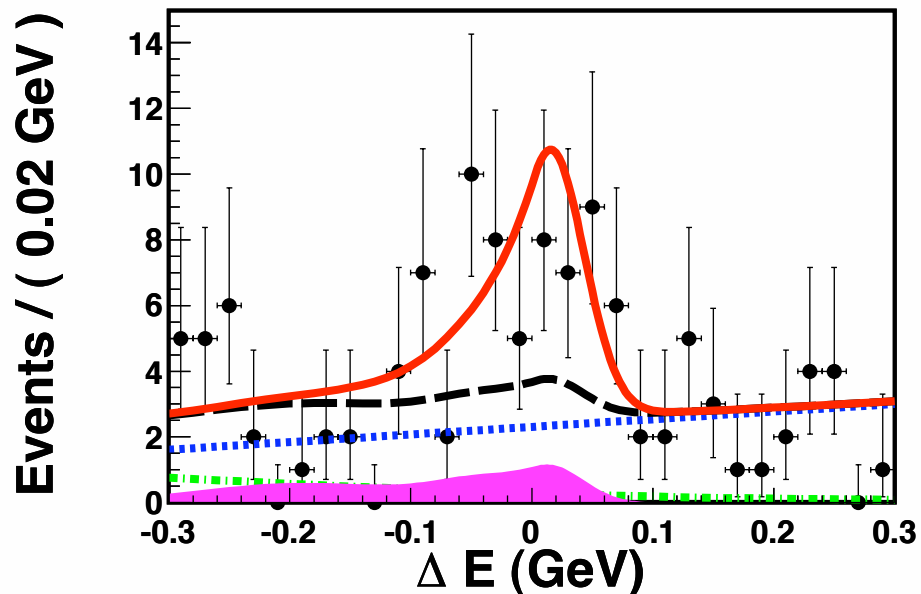- ─ **qq BG**
- ─ **b→c BG**
- ■ **Nonres+Charmless**
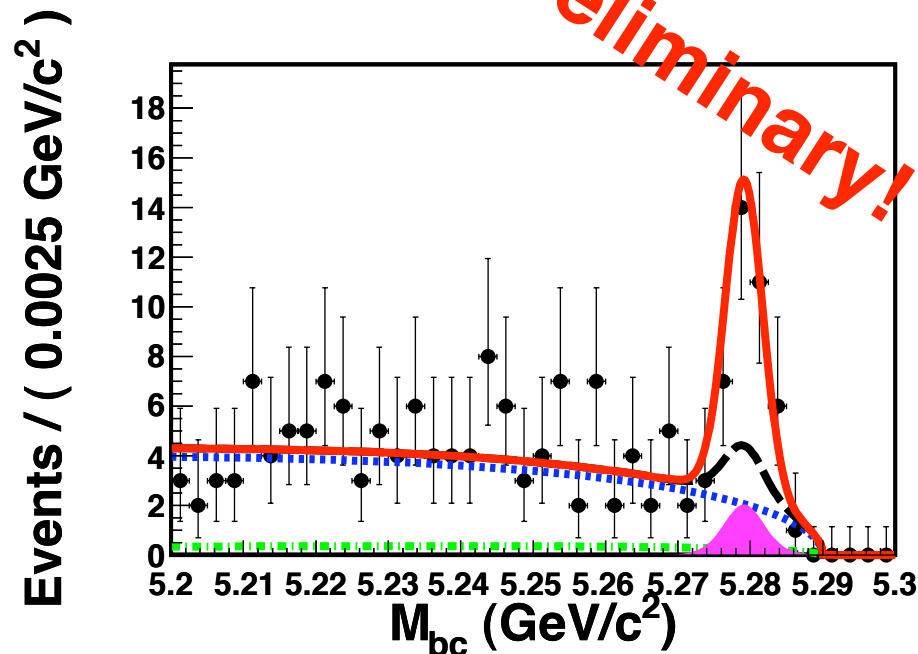
BELLE

arXiv: 0911.1779

$B^0 \rightarrow \varphi K_S \gamma$ Data

Preliminary!

35±8 Events

$\mathcal{B}(B^0 \rightarrow \varphi K_s \gamma) = (2.66 \pm 0.60 \pm 0.32) \times 10^{-6}$
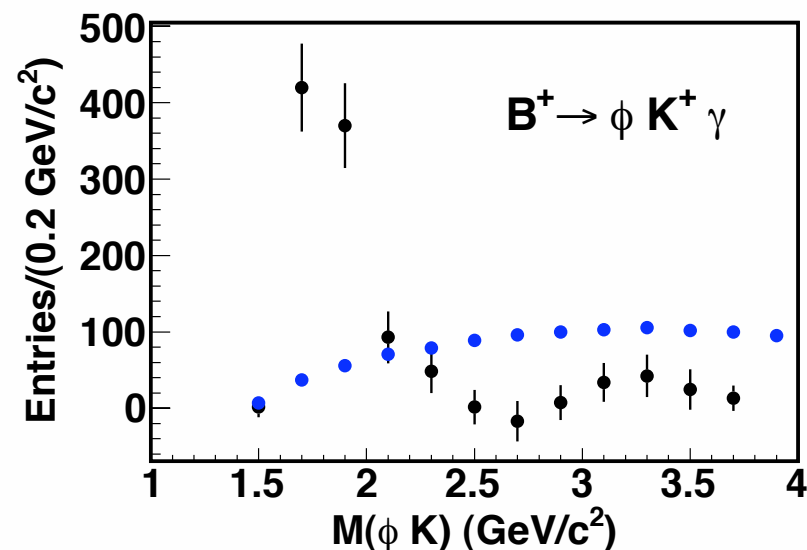
First observation
with 5.4σ significance

The neutral mode has now enough statistics for a time-dependent CPV study
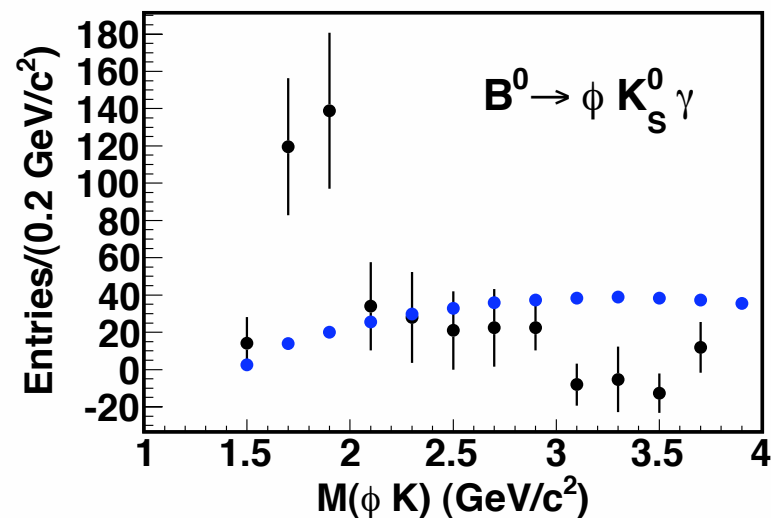
M(φK) Mass Distribution

Preliminary!

- Background subtracted and efficiency corrected M(φK) mass distribution.

- Each yield is from fit in bins of φK mass.

- Re-weighted efficiency is used for branching fraction measurement.
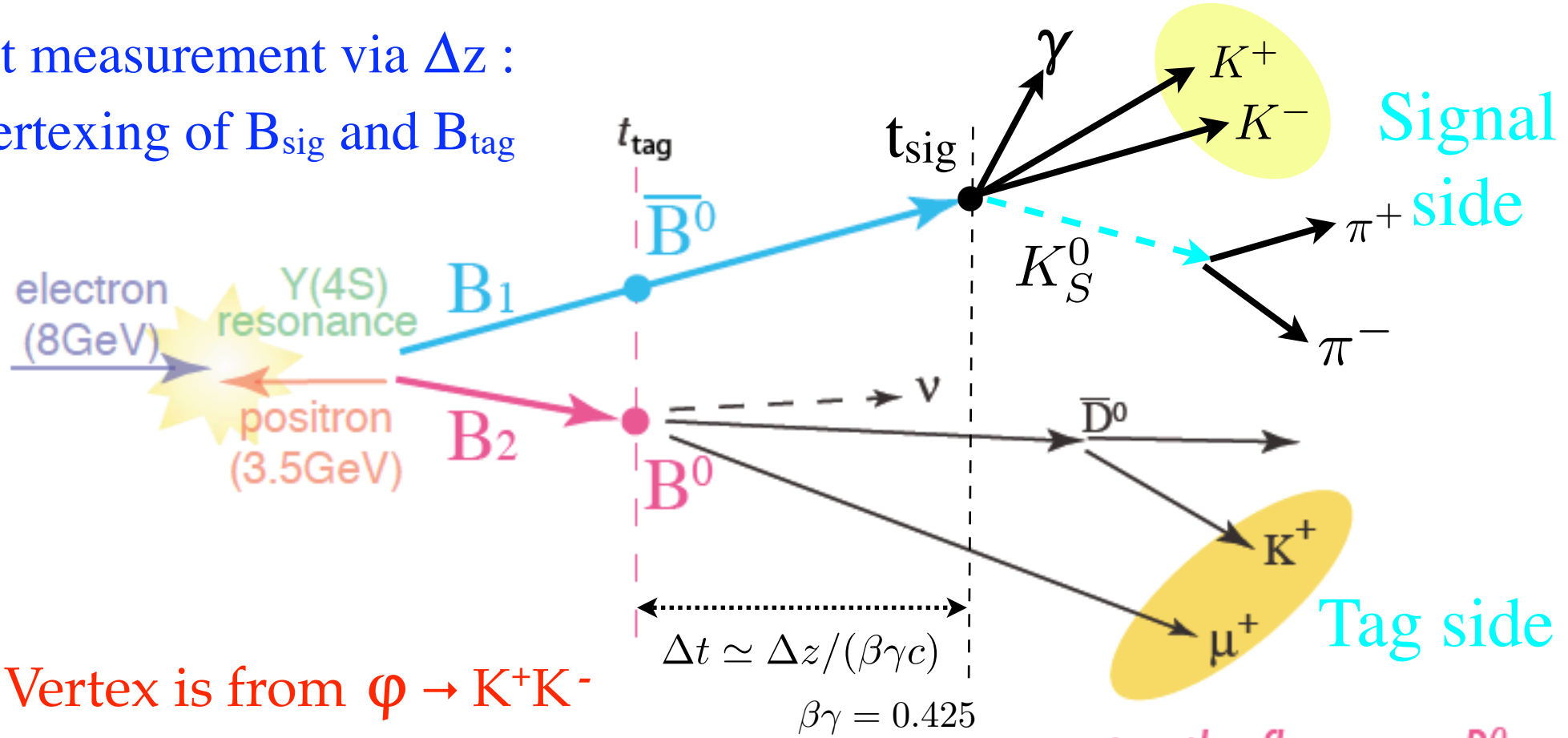
M(φK) spectrum is different from 3-body phase-space

$B^+ \rightarrow \phi \, K^+ \, \gamma$

- Data
- Phase-space

$B^0 \rightarrow \phi \, K^0_s \, \gamma$

Time-dependent Study (Vertexing)

Δt measurement via Δz :
vertexing of B_{sig} and B_{tag}

electron
(8GeV)

Y(4S)
resonance

positron
(3.5GeV)

B_1

B_2

$\overline{B}^0$

B^0

t_{tag}

t_{sig}

γ

K^+

K^-

Signal
side

K_S^0

π^+

π^-

ν

$\overline{D}^0$

K^+

μ^+

Tag side

$\Delta t \simeq \Delta z / (\beta\gamma c)$

$\beta\gamma = 0.425$

tag the flavour as B^0
by decay product(s)

Vertex is from $\varphi \rightarrow K^+K^-$
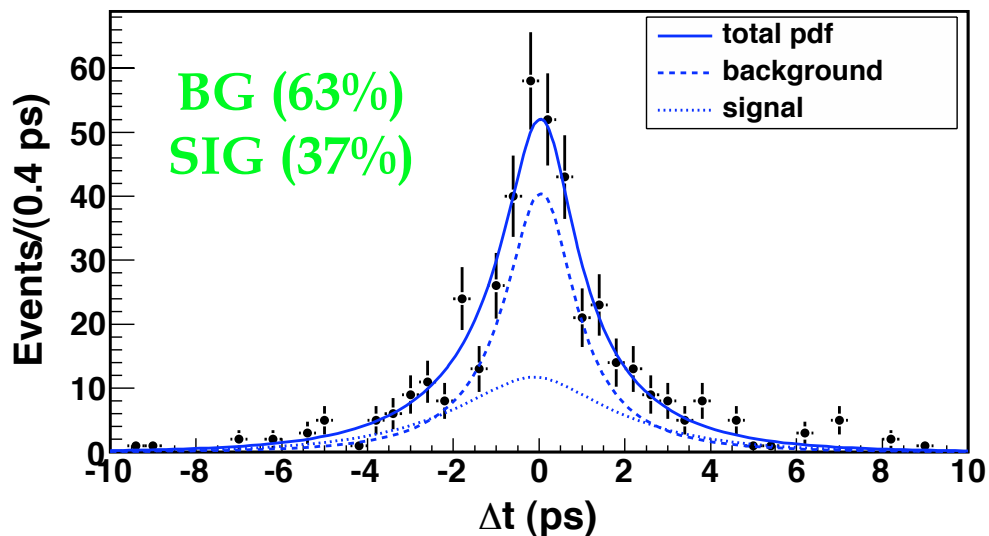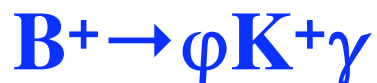(no K_S vertex is needed)

$$P(\Delta t, q; \tau_{B^0}, \Delta m_d) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ 1 + q \cdot \left[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t) \right] \right\}$$
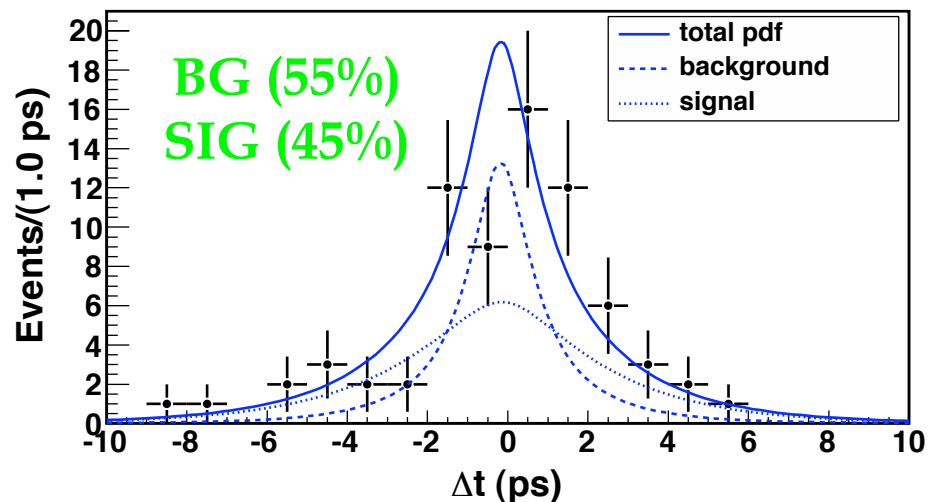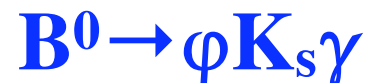
q = +1 (-1) for tagging $B^0 (\overline{B}^0)$

CP fit to the events inside signal box : (-0.2< ΔE <0.1 GeV) && (5.27< M_{bc} <5.29 GeV/c^2)

Checks for B Lifetime

$$B^+ \rightarrow \varphi K^+ \gamma$$

$$B^0 \rightarrow \varphi K_s \gamma$$

$$\tau(B^+) = 1.70 \pm 0.20 \text{ (stat) ps}$$

$$\tau(B^0) = 2.09 \pm 0.45 \text{ (stat) ps}$$

Consistent with the PDG charged (1.64 ps) and neutral (1.53 ps) B lifetimes

Nonresonant $K^+K^-K\gamma$ is included in the signal for TCPV study

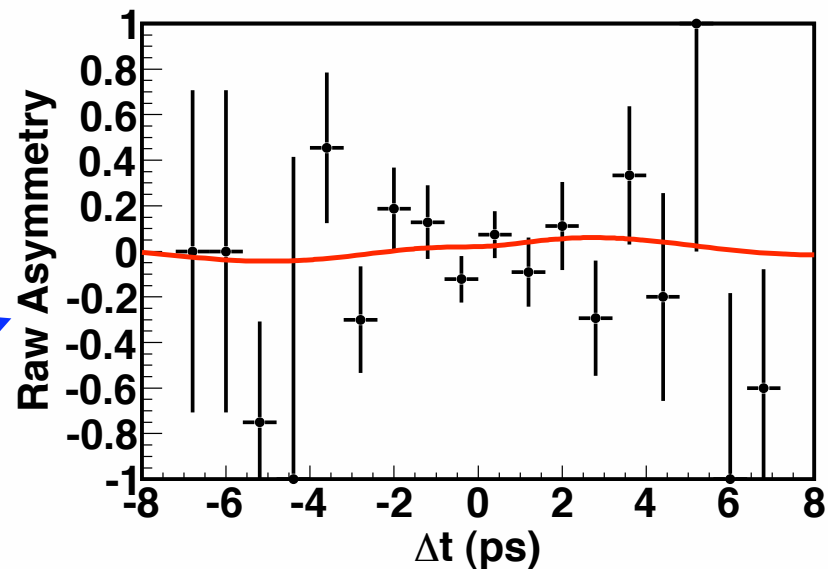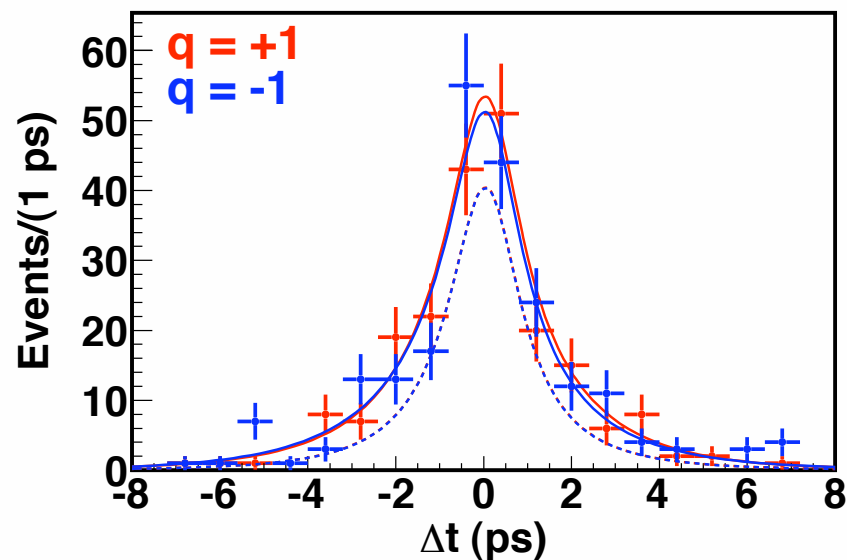# Time-dependent study of $B^+ \rightarrow \varphi K^+ \gamma$

BELLE

$772 \, \mathrm{M} \, B\overline{B}$

Preliminary!

S = 0.25±0.33 (stat)

A= 0.18±0.26 (stat)

Consistent with no CP asymmetry

$$\frac{N(q=+1)-N(q=-1)}{N(q=+1)+N(q=-1)}$$

Charge Asymmetry in B⁺→φK⁺γ

772 M B$\overline{\text{B}}$

$$A_{CP} = \frac{N(B^- \to \phi K^- \gamma) - N(B^+ \to \phi K^+ \gamma)}{N(B^- \to \phi K^- \gamma) + N(B^+ \to \phi K^+ \gamma)}$$

Preliminary!

N(B⁻) = 74±13
N(B⁺) = 79±13
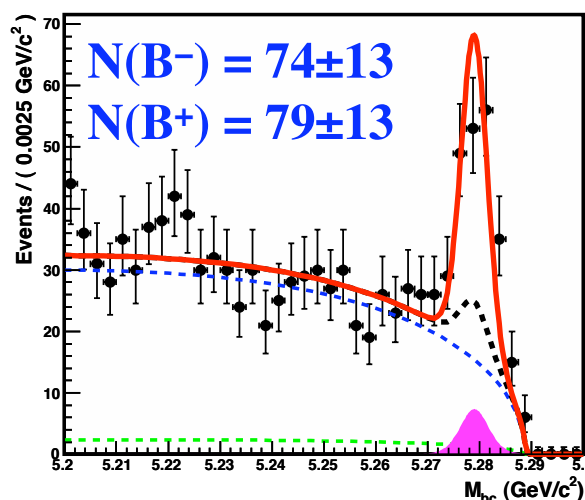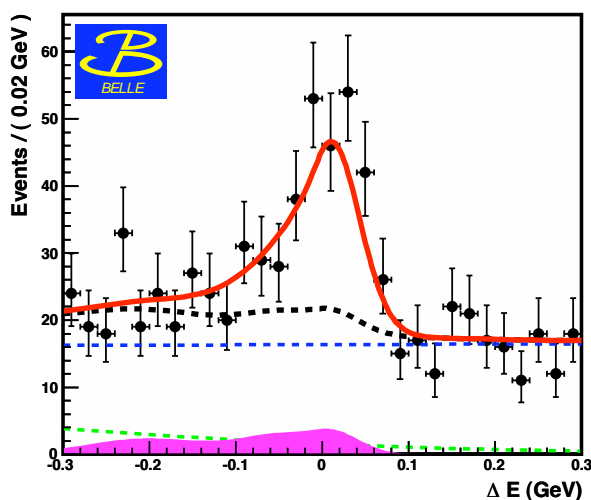
simultaneous fit to both
B⁺ and B⁻ data samples

N(B⁻→φK⁻γ)	N(B⁺→φK⁺γ)	A_{cp}
74±13	79±13	−0.03±0.11±0.08

Consistent with
no CP asymmetry
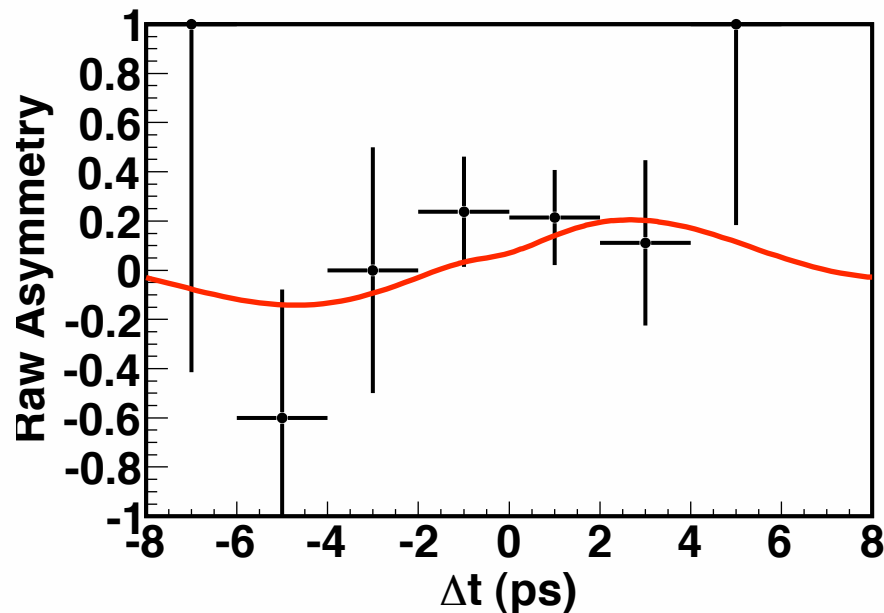
$B^0 \rightarrow \varphi K_s \gamma$ CP fit results (New!)

772 M B$\overline{\text{B}}$
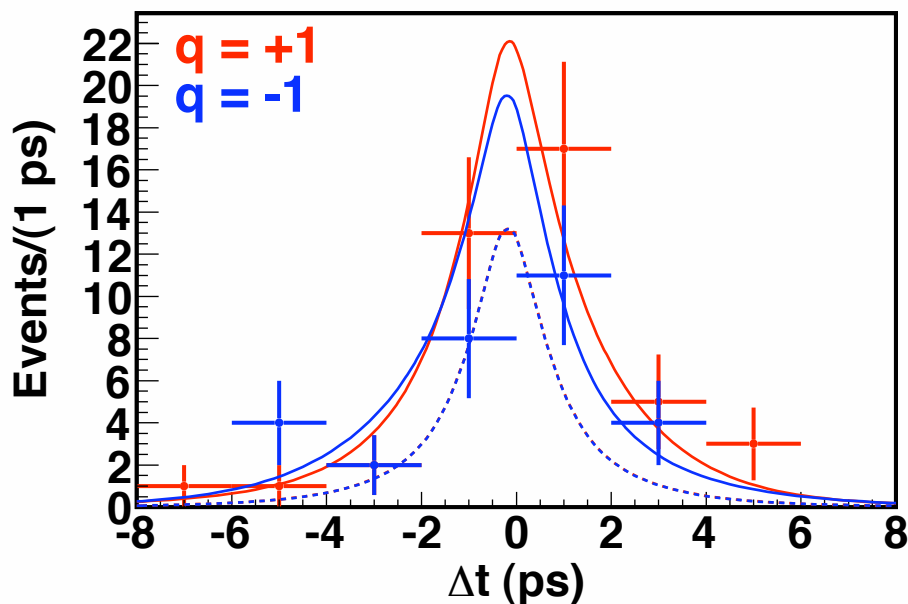
Preliminary!

$$S = 0.74^{+0.32}_{-0.45} \text{ (stat)}$$
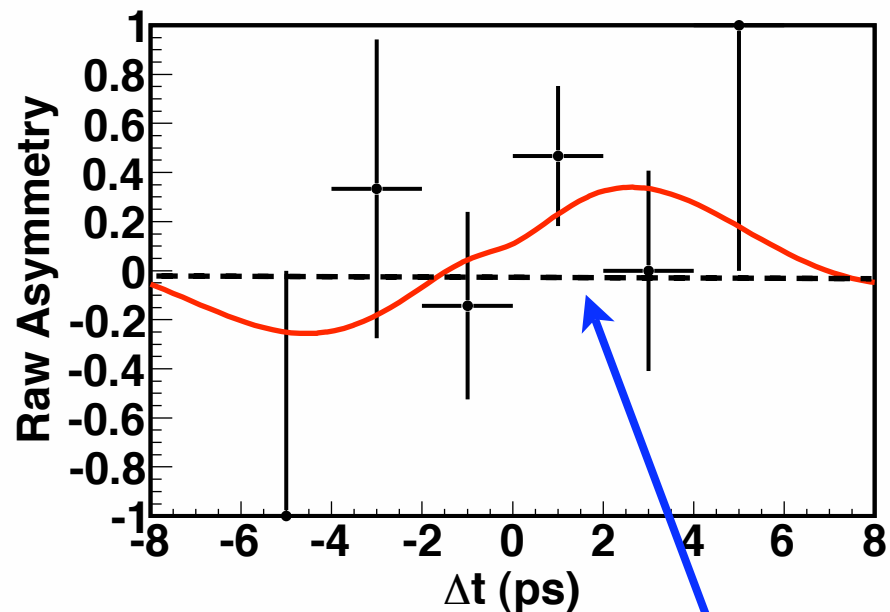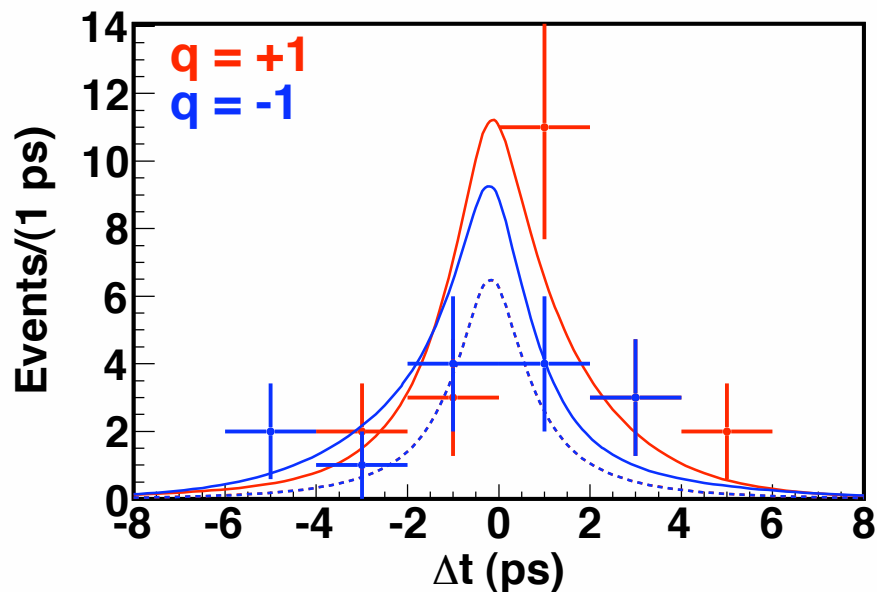$$A = 0.35 \pm 0.45 \text{ (stat)}$$

(The stat errors are from Minos)

$B^0 \rightarrow \varphi K_s \gamma$ CP fit results (New!)

772 M B$\overline{\text{B}}$

Preliminary!

Good tagged events (r>0.5)
48% of total events

Statistics Issues

- Due to low statistics and a special signal event (good-tagged, r~0.96), the error on S has a probability of 0.6%.

- We use the ±68% CL's from the residual distributions of the toy pesudo-experiments as statistical errors. **[PRD 68, 012001 (2003)]**

- We also found a bias due to low statistics (35 signal events) and include it in the systematics.

- MC simulations show that this bias significantly reduces with increase in statistics (with twice the signal, it decreases to 0.04)
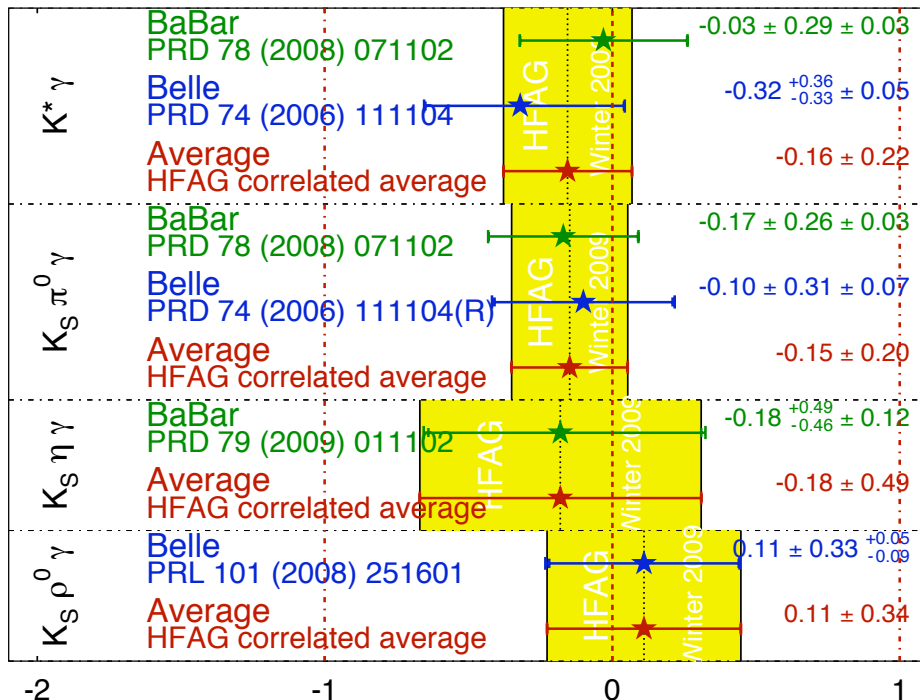

−1.05   **+0.72**

±0.58
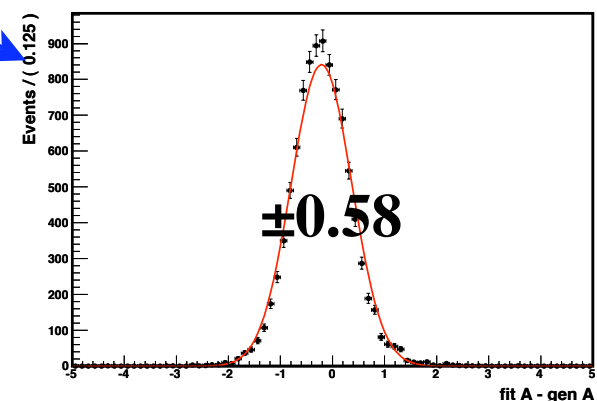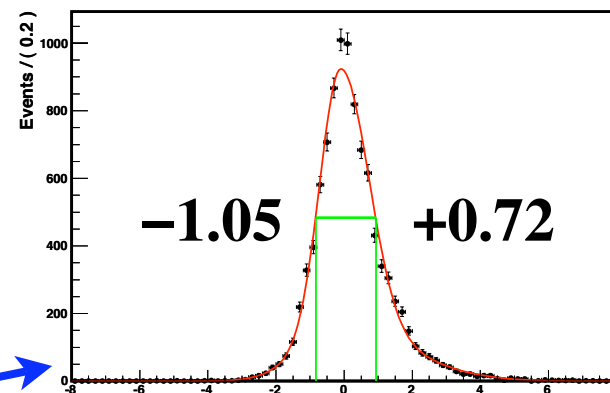
Very Preliminary!

$$S = 0.74^{+0.72}_{-1.05} \text{ (stat)} ^{+0.10}_{-0.24} \text{ (syst)}$$
$$A = 0.35 \pm 0.58 \text{ (stat)} ^{+0.23}_{-0.10} \text{ (syst)}$$
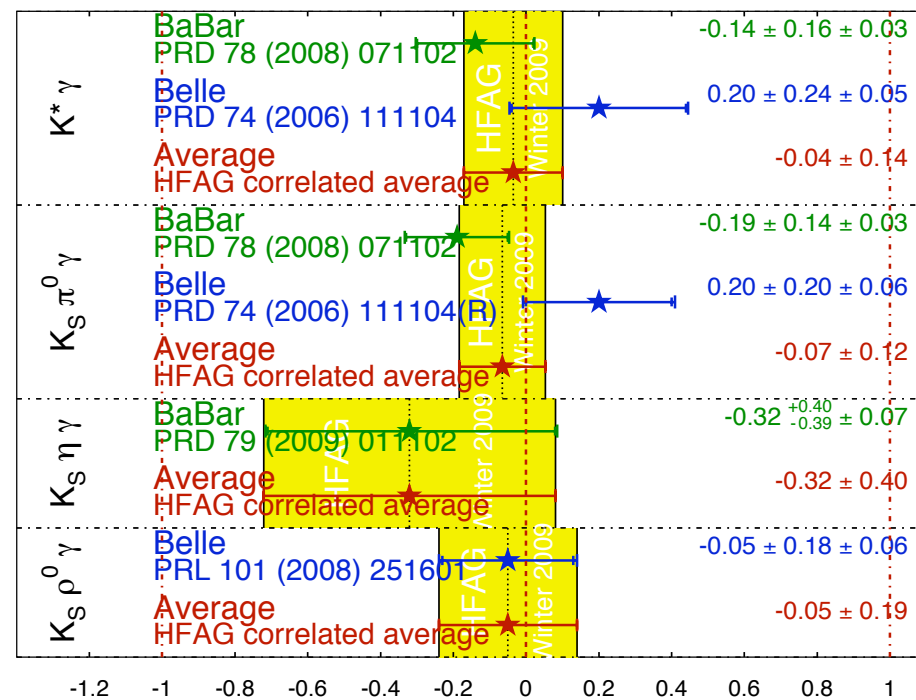
TCPV Radiative Summary

$$B^0 \rightarrow K_s \varphi \gamma \qquad S = 0.74^{+0.72}_{-1.05}\,{}^{+0.10}_{-0.24}$$

$$C = -A = -0.35 \pm 0.58\,{}^{+0.23}_{-0.10}$$

Only weak constraints on RH current with the present statistics.

Conclusion

☑ First observation of $B^0 \rightarrow \varphi K_s \gamma$ signal with 5.4 significance.

☑ The measured M(φK) distribution significantly differs from a three body phase-space decay.

☑ First measurement of time-dependent CP violation in $B^0 \rightarrow \varphi K_s \gamma$ (New!)

Very Preliminary!

$$S = 0.74^{+0.72}_{-1.05} \text{ (stat)} \ ^{+0.10}_{-0.24} \text{ (syst)}$$
$$A = 0.35 \pm 0.58 \text{ (stat)} \ ^{+0.23}_{-0.10} \text{ (syst)}$$

☑ Results are consistent with the SM expectation. No evidence so far for new physics from RH currents with the present statistics.
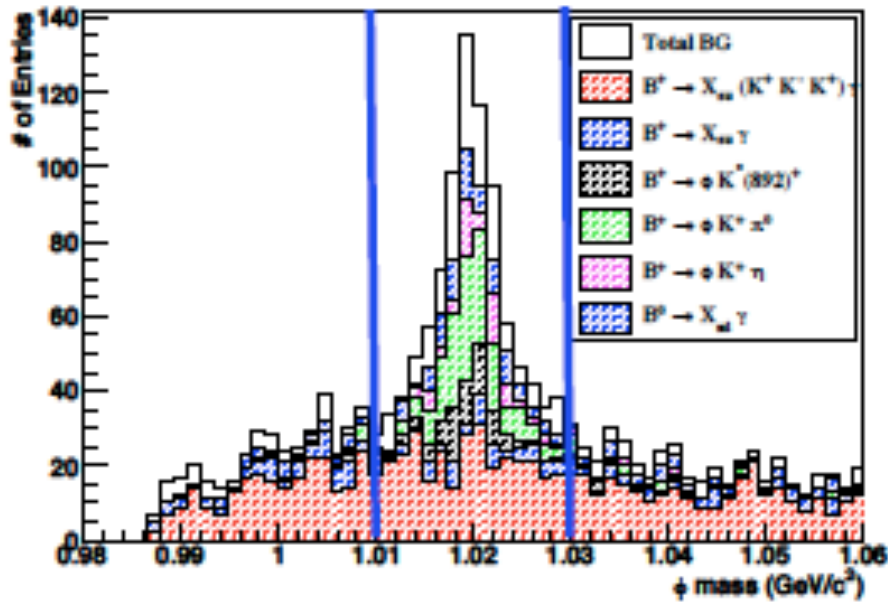
☑ Need more data to test any NP scenario (Super B factory)
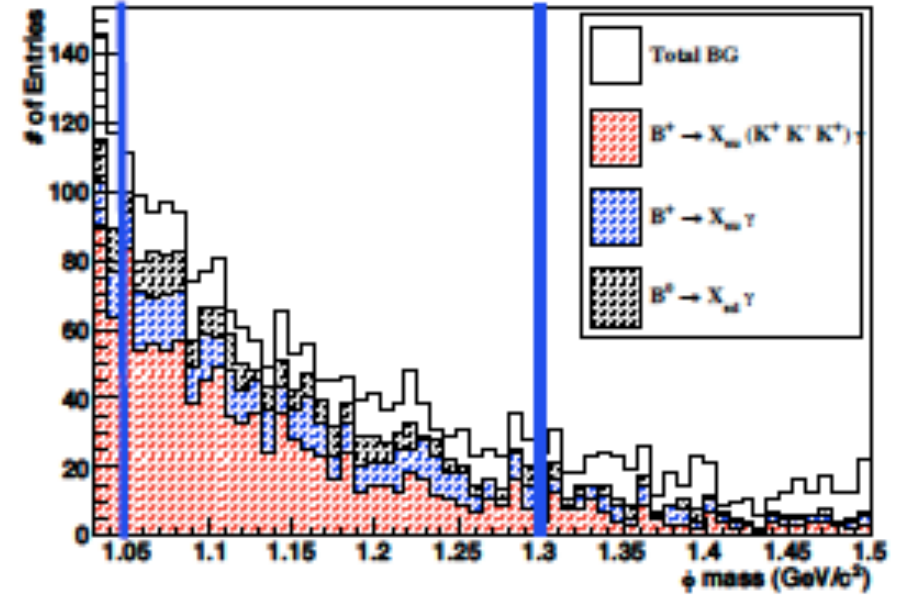
BACK UP

Systematic Errors

$B^0 \rightarrow \varphi K_s \gamma$

Parameter	$\Delta S_{\phi K_S^0 \gamma}$	$\Delta A_{\phi K_S^0 \gamma}$
Vertexing	0.08	0.04
ResolutionFunction	0.02	0.03
WrongTagFraction	0.01	0.01
PhysicsParameter	0.05	0.03
PDFShape	0.01	0.01
SignalFraction	0.03	0.07
BackgroundDTShape	0.01	0.02
FitBias	$0.00/-0.22$	$+0.21/0.00$
TSI	0.00	0.03
Total	$0.10/-0.24$	$0.23/0.10$

φ Mass Sideband

signal region : [1.01-1.03 GeV/c²]   **sideband :** [1.05-1.3 GeV/c²]

- The nonresonant $K^+K^-K\gamma$ peaks in both ΔE and M_{bc} signal region, but flat in the φ mass.

- This component is estimated to be 13% using φ sideband in data [1.05-1.3 GeV]and subtracted from the φKγ signal.

Reconstruction is in B → K* (→ Ksπ^0)γ [0.8<M(Ksπ^0)<1.0 GeV]

and also in full range of M(K$_S\pi^0$) :

$$M_{K\pi} < 1.8\text{GeV}$$

Reconstructed variables:

Energy difference : $\Delta E \equiv E_B^{\text{c.m.s.}} - E_{\text{beam}}^{\text{c.m.s.}}$
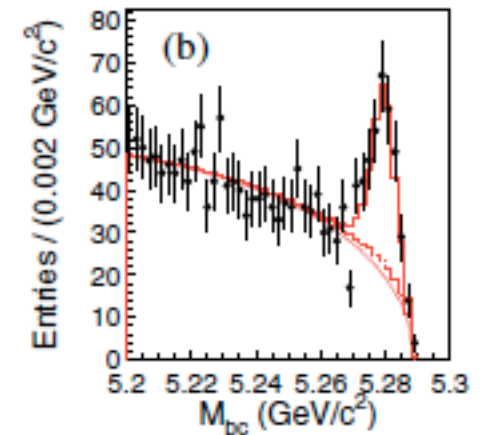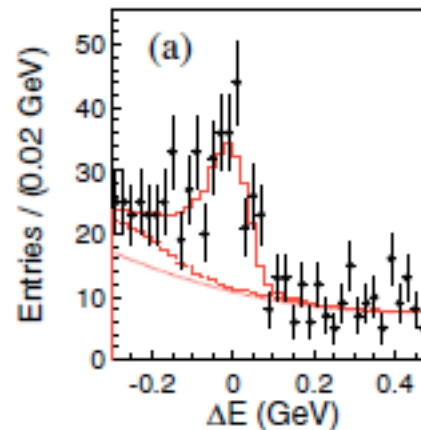
Beam-energy constrained mass :

$$M_{\text{bc}} \equiv \sqrt{(E_{\text{beam}}^{\text{c.m.s.}})^2 - (p_B^{\text{c.m.s.}})^2}$$

.... **qq BG**

TCPV to the events in the signal-box

Signal extraction : ΔE-M$_{bc}$ 2D fit

Signal region :

$$-0.2\text{GeV} < \Delta E < 0.1\text{GeV}$$

$$5.27\text{GeV}/c^2 < M_{\text{bc}} < 5.29\text{GeV}/c^2$$

406 events in the signal-box

==>Vertex is from Ks →$\pi^+\pi^-$ (both pions are required
to have enough hits in the silicon)

$$P(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q[S\sin(\Delta m_d \Delta t) + A\cos(\Delta m_d \Delta t)]\}.$$

==> measurement for Ks$\pi^0\gamma$:

$$M_{K\pi} < 1.8\text{GeV}$$

$$S_{K_S\pi^0\gamma} = -0.10 \pm 0.31 \pm 0.07$$
$$A_{K_S\pi^0\gamma} = -0.20 \pm 0.20 \pm 0.06$$

and also for B → K* (→ Ksπ^0)γ :
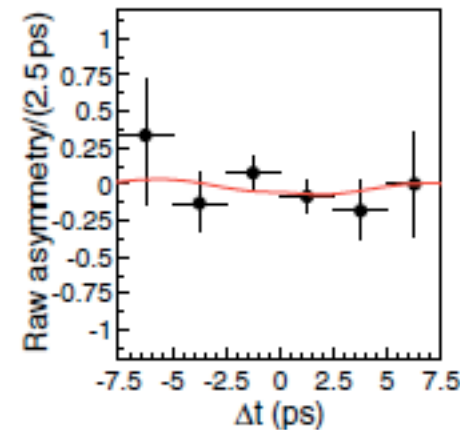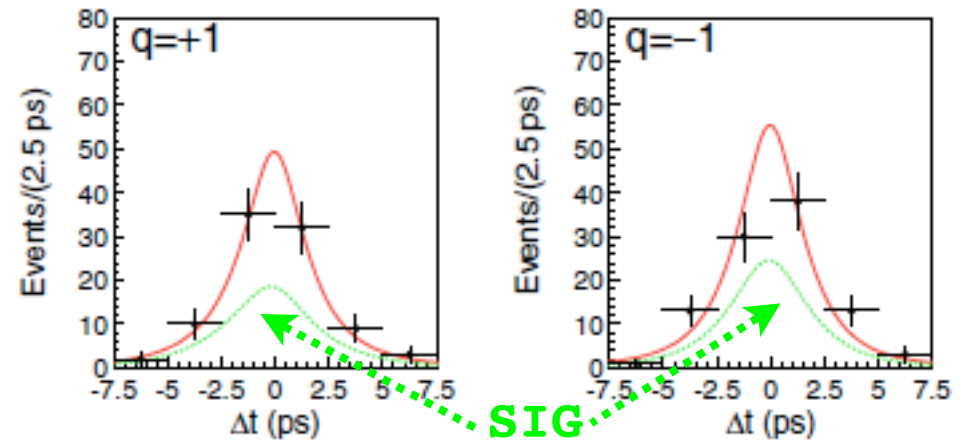
[0.8<M(Ksπ^0)<1.0 GeV]

$$S_{K^*\gamma} = -0.32^{+0.36}_{-0.33} \pm 0.05$$
$$A_{K^*\gamma} = -0.20 \pm 0.24 \pm 0.05$$

r>0.5

==> consistent with the SM expectation.

TCPV in B→K$_S$ρ^{0}γ

=>Vertex is from ρ⁰→π⁺π⁻ (no K$_S$ vertex is needed)

B → K$_S$ρ⁰γ candidates are selected from K$_S$π⁺π⁻γ sample :

M(π⁺π⁻) invariant mass is required to be consistent with a ρ⁰ meson.

0.6<M(π⁺π⁻)<0.9 GeV/c²

contributions from other modes : B → K*⁺π⁻γ

Signal Extraction : using M$_{bc}$ distribution

$$-0.1 < \Delta E < 0.08 \text{GeV}$$

Effective CP violation parameters are measured and corrected for the dilution.

N_sig = (212±17) events
B→K$_S$π⁺π⁻γ
—— Signal
······· qq BG

B⁺ (a)

B⁰ (b)

BELLE
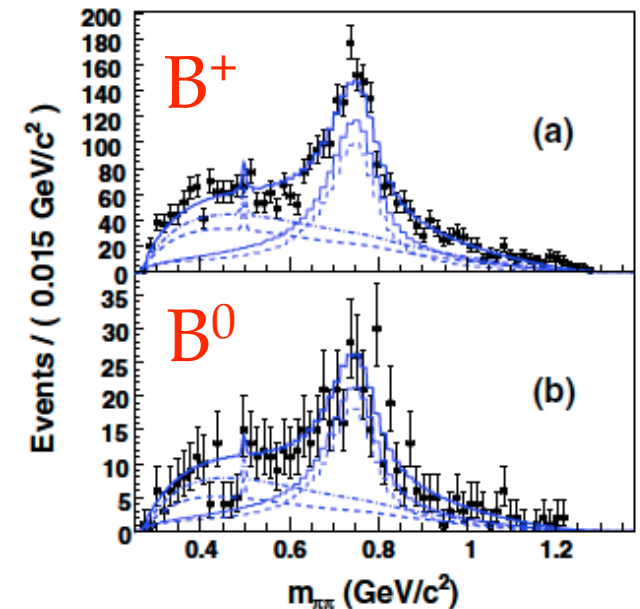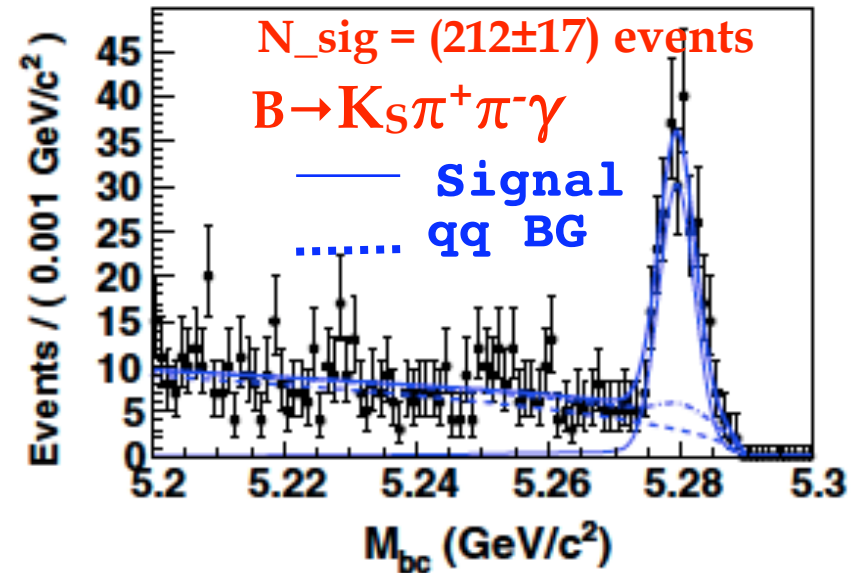
Effective CP violation parameters in the ρ^0 region :

for $M(K_S\pi^+\pi^-) < 1.8$ GeV and $0.6 < M(\pi^+\pi^-) < 0.9$ GeV/c²

N_sig = (212±17) events

$$\mathcal{S}_{\text{eff}} = 0.09 \pm 0.27^{+0.04}_{-0.07}$$

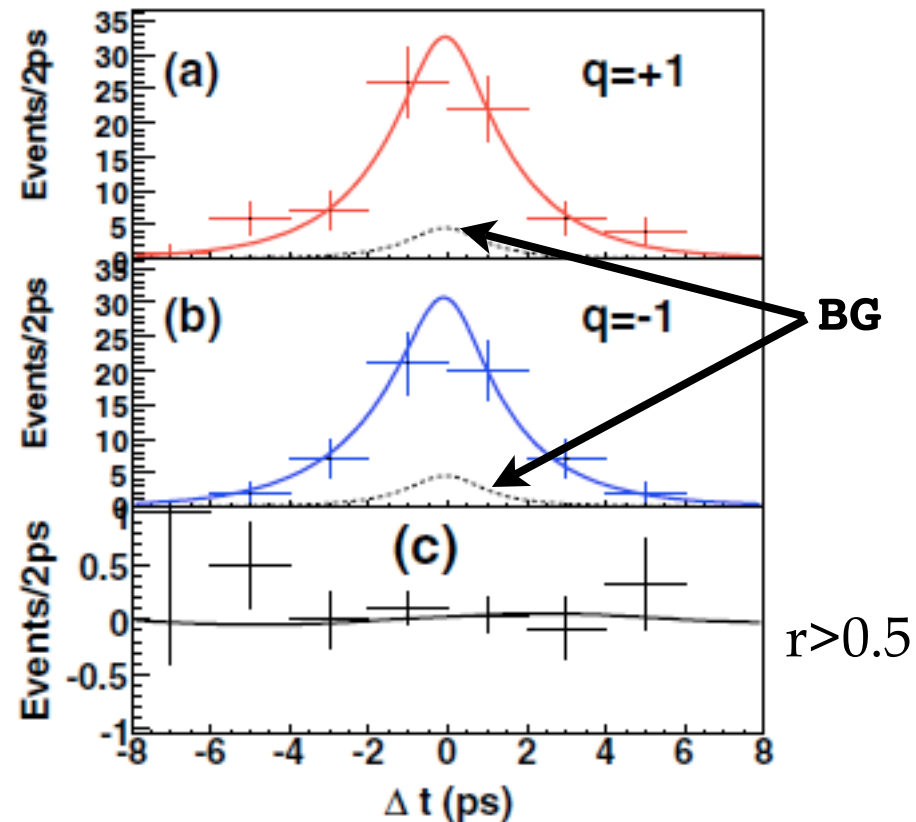$$\mathcal{A}_{\text{eff}} = 0.05 \pm 0.18 \pm 0.06$$

dilution due to $\mathcal{B}(B \to K^{*+}\pi^-\gamma)$ (not self-conjugate)

$$\mathcal{D} = 0.83^{+0.19}_{-0.03}$$

$$\mathcal{S}_{K_S\rho^0\gamma} = 0.11 \pm 0.33(\text{stat})^{+0.05}_{-0.09}(\text{syst})$$

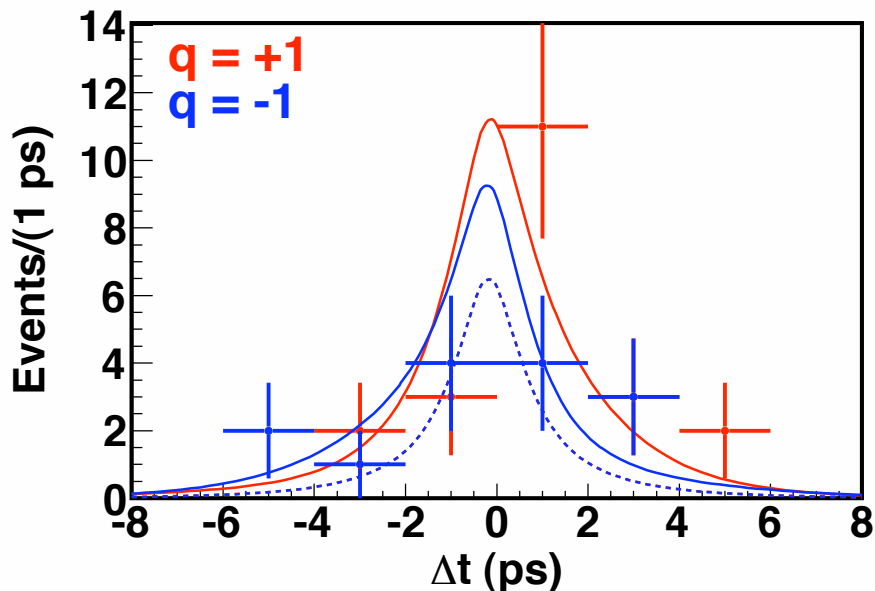**==> consistent with the SM expectation.**

BG

r>0.5

B[0]→φK_sγ CP fit results (New!)

$B^0 \rightarrow \varphi K_s \gamma$ CP fit results (New!)

Preliminary!

Good tagged events (r>0.5)
48% of total events

SM Prediction

$S = 0.74^{+0.32}_{-0.45}$ (stat)
$A = 0.35 \pm 0.45$ (stat)

(The stat errors are from Minos)